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CONSERVATION AND SOLAR GUIDELINES*

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ABSTRACT

Guidelines are given for selecting R-values and infiltration levels, and determining the size of the solar collection area for passive solar buildings. The guidelines are based on balancing the incremental cost/benefit of conservation and passive solar strategies. Tables are given for 90 cities in the US and the results are also displayed on maps. An example is included.

1. INTRODUCTION

During the last few years, a conclusion has been expressed repeatedly: good passive solar design involves a balance of conservation and solar gains, and the proper balance depends on the climate. This conclusion is independently reached by cost/benefit studies using computer models and by practitioners designing and building across the country. By conservation we mean added insulation and decreased air infiltration to reduce the gross heating energy required to maintain winter comfort. By passive solar we mean adding south windows, Trombe walls, or sunspaces to supply some of this gross heat. The net heat required by the building is the gross heat minus the solar savings. Conservation makes the passive solar system's job easier; likewise, passive solar reduces the need for auxiliary heat well below levels attainable by conservation alone. Good thermal design consists of achieving a proper balance of these two strategies.

The purpose of this paper is to present a quantitative but simple set of guidelines for balancing conservation and solar that takes proper account of the solar and weather characteristics of each location. The guidelines are not a substitute for thermal evaluation later in the design process, but do provide a reasonable starting point for schematic design. They are applicable to residential buildings and small commercial buildings having residential levels of internal gains (30-60 Btu/ft^2 per day).

The two guidelines will be presented first; an explanation of their development follows.

2. GUIDELINE 1. CONSERVATION LEVELS

Recommended levels of insulation and building airtightness can be computed based on a conservation factor (CF). Two suggested levels of CF, corresponding to two different projected fuel costs, are given in Table I for 90 cities. Unless conditions indicate otherwise, use the CF values corresponding to high fuel cost as a starting point.

Use the following formulas to compute guidance values for insulation and airtightness levels.

$$R_{wall} = 14 \cdot CF$$
$$R_{ceiling} = 22 \cdot CF$$
$$R_{perimeter} = 13 \cdot CF - 5$$
$$R_{basement} = 16 \cdot CF - 8$$
$$N_{E,W,N} = 1.7 \cdot CF$$
$$ACH = 0.42/CF$$

Based on guidance resulting from these formulas, select practical, buildable conservation levels as a starting point for the design, trying for the most part to stay within 20% of the guidance. For windows choose the closest integer value.

R_{wall} and $R_{ceiling}$ are the overall R-values (h °F ft^2/Btu) of the opaque wall and ceiling insulation, accounting for the series effect of all air layers and materials, including the attic air space, if any.

$R_{perimeter}$, which refers to slab-on-grade construction, is the R-value of insulation

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TABLE I: GUIDELINE VALUES OF CONSERVATION FACTOR, LOAD COLLECTOR RATIO, AND SOLAR SAVINGS FRACTION

	Low Fuel Cost			High Fuel Cost		
	CF	LCR	SSF(%)	CF	LCR	SSF(%)
BIRMINGHAM, ALABAMA	.95	117	31	1.19	41	58
PHOENIX, ARIZONA	.70	123	53	.83	66	74
WINSLOW, ARIZONA	1.13	46	57	1.35	25	75
LITTLE ROCK, ARKANSAS	1.04	97	31	1.30	34	59
FRESNO, CALIFORNIA	.91	100	39	1.12	47	60
LOS ANGELES, CA	.70	96	70	.81	61	84
RED BLUFF, CALIFORNIA	.92	116	34	1.14	47	58
SACRAMENTO, CA	.93	102	40	1.15	46	60
SAN FRANCISCO, CA	.89	70	64	1.04	42	78
COLORADO SPRINGS, CO	1.30	33	60	1.55	18	78
DENVER, COLORADO	1.27	36	57	1.52	19	76
GRAND JUNCTION, CO	1.27	45	47	1.56	21	69
HARTFORD, CONNECTICUT	1.42	137	13	1.88	36	29
WILMINGTON, DELAWARE	1.25	90	23	1.62	28	47
WASHINGTON, DC	1.25	97	21	1.64	30	45
APALACHICOLA, FLORIDA	.69	173	39	.82	74	65
ORLANDO, FLORIDA	.50	272	46	.59	134	70
ATLANTA, GEORGIA	1.00	101	32	1.24	37	59
BOISE, IDAHO	1.31	64	33	1.67	28	51
CHICAGO, ILLINOIS	1.39	121	15	1.63	34	32
SPRINGFIELD, ILLINOIS	1.37	98	19	1.73	28	42
EVANSVILLE, INDIANA	1.21	121	19	1.58	34	42
INDIANAPOLIS, INDIANA	1.33	158	12	1.76	40	30
BURLINGTON, IOWA	1.39	91	19	1.82	27	41
MASON CITY, IOWA	1.56	81	18	2.07	25	36
DODGE CITY, KANSAS	1.21	49	45	1.49	22	69
LEXINGTON, KENTUCKY	1.23	131	17	1.60	35	39
LAKE CHARLES, LA	.72	219	28	.89	73	57
NEW ORLEANS, LA	.70	176	36	.85	71	64
CARIBOU, MAINE	1.72	92	14	2.29	33	25
PORTLAND, MAINE	1.52	103	15	2.02	32	30
BALTIMORE, MARYLAND	[illegible]	92	24	1.58	29	48
BOSTON, MASSACHUSETTS	1.33	113	17	1.75	32	37
DETROIT, MICHIGAN	1.40	168	11	1.85	47	24
TRAVERSE CITY, MI	1.54	191	8	2.04	63	16
INT. FALLS, MINNESOTA	1.80	148	8	2.39	59	14
MINNEAPOLIS, MN	1.60	126	11	2.13	39	23
JACKSON, MISSISSIPPI	.86	133	32	1.06	48	60
COLUMBIA, MISSOURI	1.26	97	21	1.64	28	46
KANSAS CITY, MISSOURI	1.29	80	25	1.67	25	50
SAINT LOUIS, MISSOURI	1.22	97	23	1.58	29	48
BILLINGS, MONTANA	1.47	57	29	1.91	22	48
DILLON, MONTANA	1.55	41	37	1.98	18	55
GREAT FALLS, MONTANA	1.51	64	25	1.97	26	41
OMAHA, NEBRASKA	1.43	72	23	1.87	22	47
NORTH PLATTE, NEBRASKA	1.41	44	39	1.77	18	62
ELY, NEVADA	1.41	30	59	1.70	16	76
LAS VEGAS, NEVADA	.86	80	55	1.02	43	75
RENO, NEVADA	1.23	38	60	1.47	21	77
CONCORD, NEW HAMPSHIRE	1.51	123	12	2.01	36	27
NEWARK, NEW JERSEY	1.27	99	21	1.65	29	44
ALBUQUERQUE, NM	1.08	48	58	1.29	26	77
LOS ALAMOS, NM	1.29	33	61	1.53	18	79
ALBANY, NEW YORK	1.47	160	10	1.95	42	24
BINGHAMTON, NEW YORK	1.50	269	6	1.99	70	15
BUFFALO, NEW YORK	1.47	261	7	1.94	70	15
NEW YORK (CENTRAL)	1.25	146	15	1.64	37	36
ASHEVILLE, NC	1.14	67	38	1.42	27	63
RALEIGH, NORTH CAROLINA	1.06	88	33	1.32	33	59
BISMARCK, NORTH DAKOTA	1.67	82	16	2.22	29	29
CLEVELAND, OHIO	1.39	231	8	1.84	62	19
COLUMBUS, OHIO	1.34	184	11	1.78	46	26
OKLAHOMA CITY, OK	1.07	77	37	1.33	30	64
MEDFORD, OREGON	1.22	90	27	1.56	38	43
NORTH BEND, OREGON	1.11	55	53	1.35	29	69
PORTLAND, OREGON	1.21	120	21	1.55	46	36
PHILADELPHIA, PA	1.25	103	20	1.62	30	44
PITTSBURGH, PA	1.37	208	9	1.81	54	22
PROVIDENCE, RI	1.37	92	19	1.79	28	40
CHARLESTON, SC	.84	129	35	1.03	51	62
RAPID CITY, SD	1.48	52	31	1.90	20	52
SIOUX FALLS, SD	1.56	83	18	2.07	26	35
MEMPHIS, TENNESSEE	1.02	117	27	1.29	37	55
NASHVILLE, TENNESSEE	1.10	147	18	1.42	39	44
AMARILLO, TEXAS	1.08	52	54	1.30	26	75
CORPUS CHRISTI, TEXAS	.58	260	35	.70	108	62
DALLAS, TEXAS	.87	118	35	1.06	46	63
EL PASO, TEXAS	.88	74	58	1.04	40	77
SAN ANGELO, TEXAS	.84	103	44	1.01	47	69
BRYCE CANYON, UTAH	1.49	24	65	1.77	14	80
SALT LAKE CITY, UTAH	1.31	50	41	1.64	22	61
BURLINGTON, VERMONT	1.56	229	7	2.08	64	15
NORFOLK, VIRGINIA	1.05	85	34	1.31	33	60
ROANOKE, VIRGINIA	1.16	78	31	1.47	28	57
SEATTLE, WASHINGTON	1.25	112	22	1.60	48	35
SPOKANE, WASHINGTON	1.44	109	17	1.88	44	28
CHARLESTON, WV	1.21	169	14	1.58	42	34
GREEN BAY, WISCONSIN	1.58	110	13	2.10	37	25
MADISON, WISCONSIN	1.55	95	16	2.05	30	31
CASPER, WYOMING	1.44	34	50	1.78	16	70

added to the outside of foundation walls or under the slab perimeter. Normally this is rigid insulation installed below grade against foundation walls down to the footing or 2 feet wide under the slab. For a floor built over a crawl space, use either the floor insulation R-value for the frame floor or the perimeter insulation value outside the stem wall down to the footings.

$R_{basement}$ refers to a heated basement and is the R-value of the insulation outside the exterior basement walls extending 4 feet below grade. Use 1/2 this R-value from 4 feet below grade down to the top of the basement-wall footings. Use this same strategy for fully bermed walls.

$N_{E,W,N}$ refers to the number of window glazings to be used on east, west, and north windows. However, if this number exceeds 3, consider using either double glazing combined with movable insulation or using a low-conduction glazing with U-value less than 0.3 Btu/h °F ft^2.

ACH refers to the effective air changes per hour resulting from natural infiltration and forced ventilation; it is the sum of the natural infiltration and the non-heat-recovered portion of the forced ventilation. If a heat recovery unit is used for forced ventilation, the non-heat-recovered portion is equal to

$$\left(1 - \begin{array}{c}\text{heat recovery}\\ \text{effectiveness}\\ \text{factor}\end{array}\right) \cdot ACH_{forced} \quad .$$

If the guidance value is less than ACH = 0.5 air changes per hour, forced ventilation is recommended using a heat recovery unit to maintain adequate indoor-air quality. For commercial applications or situations with unusually high sources of indoor-air pollution, higher ventilation levels may be required.

3. GUIDELINE 2. PASSIVE SOLAR GLAZING AREA

The primary solar parameter of the building is the load collector ratio, LCR. This is defined as follows:

$$LCR = \frac{NLC}{A_p} \quad ,$$

where NLC is the net load coefficient, excluding losses through the solar wall (Btu/°F day), and A_p is the projected area of the solar wall glazing, ft^2. See Ref. 1 or 2 for a more complete definition of these terms. (NLC is the same as BLC in Ref. 2.)

Recommended values of LCR are given in Table I; however, to use these values, an estimate of NLC must somehow be obtained. NLC depends on the conservation level achieved. If the recommendations of Guideline 1 have been followed, NLC can be computed approximately as follows:

$$NLC = \frac{GF \cdot A_f}{CF} \quad ,$$

where GF is a geometry factor that accounts for the relative dimensions of the building and A_f is the gross floor area. Suggested values of GF are given in Table II.

TABLE II

GEOMETRY FACTOR, GF

Floor Area	Number of Stories 1	2	3	4
1000	7.3			
1500	6.5	6.7		
3000	5.4	5.4	5.7	
5000	4.9	4.7	4.9	5.1
10000	4.3	4.0	4.0	4.2
20000	3.9	3.5	3.5	3.5

The projected area, A_p, can now be determined as follows:

$$A_p = \frac{NLC}{LCR} \quad .$$

As a starting point for design, the combined projected area of all passive system types should be within 20% of this value. The recommendation is independent of the choice of passive system type or types.

4. BACK-UP HEAT

At this point, a very rough estimate of annual auxiliary heat, Q_{aux}, can be obtained from the relation

$$Q_{aux} = DD \cdot NLC \cdot (1 - SSF) \quad ,$$

where DD is the degree days for the location and SSF is the solar savings fraction.

SSF values will depend on system type. Values of SSF for reference design SSD1, a semienclosed sunspace with 50° sloped glazing (see Ref. 1 or 2) are given in Table I. For other passive system types, refer to the LCR tables in Appendix F of Ref. 2.

5. EXAMPLE

Determine conservation and solar guidelines for a 1500 ft^2 house in Denver, Colorado.

Table I values, using high fuel cost, are

$$CF = 1.52 \ ,$$
$$LCR = 19 \ , \text{ and}$$
$$SSF = 0.76 \ .$$

Therefore, guidance values are as follows:

		Recommended Range
R_{wall}	$= 14 \times 1.52 = 21$	17 to 25
$R_{ceiling}$	$= 22 \times 1.52 = 33$	27 to 40
$R_{perimeter}$	$= 13 \times 1.52 - 5 = 15$	12 to 18
$R_{basement}$	$= 16 \times 1.52 - 8 = 16$	13 to 19
$N_{E,W,N}$	$= 1.7 \times 1.52 = 2.6$	2 or 3
ACH	$= 0.42/1.52 = 0.28$	0.22 to 0.34

For a 1500 ft^2, single-story building,

$$GF = 6.5, \text{ from Table II} \ .$$

Therefore, if the conservation guidance is followed,

$$NLC = 6.5 \times 1500/1.52 = 6410 \text{ Btu/}^{\circ}\text{F day} \ .$$

$$A_p = 6410/19 = 340 \text{ ft}^2 \ .$$

For Denver, the degree days (base 65°F) are 6018. Therefore,

$$Q_{aux} = 6018 \times 6410 \times (1 - 0.76) = 9.2 \text{ million Btu/year} \ .$$

All these estimates, of course, are subject to updating as the design proceeds. However, they do give valuable guidance for beginning the design.

6. MAPS

Maps of CF, LCR, and SSF (for a semienclosed sunspace) based on values at 219 locations are given in Figs. 1-3.

7. BASIS FOR THE GUIDELINES

Table I has been developed based on balancing the incremental cost/benefit of conservation and solar strategies as outlined in Refs. 2 and 3. Each case in Table I represents an economic life-cycle cost optimum for each city for identical assumed fuel costs and financial parameters. Thus the table shows how the optimum mix varies with climate.

To obtain simple guidelines, assumed values have been used for the incremental cost of passive solar aperture, conservation improvements, the cost of heat, the escalation rate of the cost of heat, and the fixed charge rate. Note, however, that the guidelines depend on cost ratios and, thus, will not change with inflation if all costs escalate proportionally. The "high fuel cost" column in Table I is intended to represent the cost of electric resistance heat in much of the US (about 6.5¢/kWh in 1983 dollars); the "low fuel cost" column is based on one-half of the high fuel cost.

The formula for NLC is based on the premise that conservation levels will be set based on the conservation guidelines. If different conservation levels are used, A_p should be based on a realistic estimate of NLC and the recommended value of LCR.

The guidelines are based on heating-season performance only. Nevertheless, summer cooling should also be a major concern to the designer, especially in the hotter areas of the nation. The first strategy should always be a good defense. This consists primarily of avoiding solar gains in the summer through effective window placement and shading. Deciduous trees are particularly effective to the east and west of the building but should not be used in the south 120° sector. Various passive cooling strategies can also be used. Most importantly, care should be taken to insure that the passive heating system does not exacerbate the cooling load. Full shading may be warranted in some areas; several studies have indicated that unless this is done, diffuse solar gains alone will significantly add to the cooling load. Preliminary results from studies by McFarland and Jones at Los Alamos indicate that Trombe walls and water walls result in the least cooling load, sunspaces are next (depending on glazing slope), and direct gain usually results in the greatest cooling load. Sloped glazing should probably be avoided (or well shaded in the summer) on sunspaces in the warmest climates. East and west sunspace glazing should be minimized in all locations, and adequate summer venting capability should be provided.

8. COST ASSUMPTIONS

As shown in Ref. 3, a global optimum is achieved when $D = a/h$,

where $D = d(SSF)/d(1/LCR)$, (derivative of SSF with respect to 1/LCR),

a = incremental cost of the passive system, dollars per ft^2 of projected area,

$h = CH \cdot FF \cdot DD/FCR$,

CH = current cost of heat delivered to the building, \$/Btu,

FF = levelization factor (see Ref. 4), dimensionless, and

FCR = fixed charge rate (see Ref. 4), yr^{-1}.

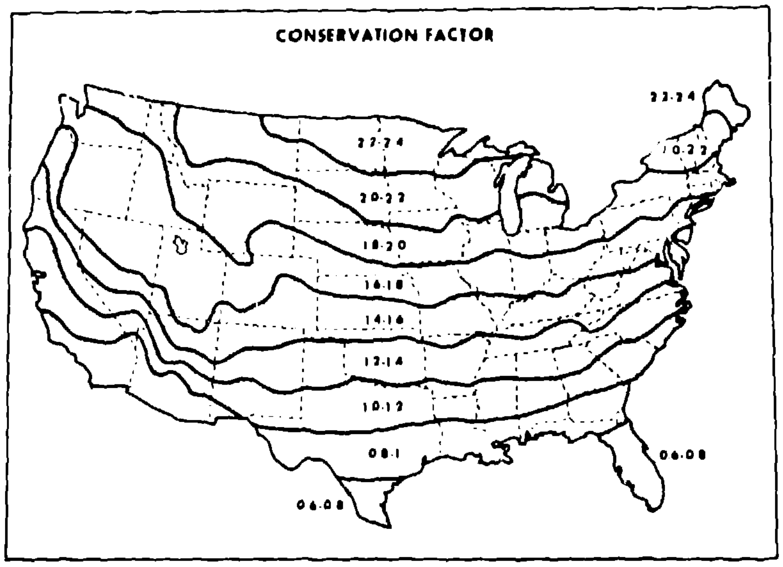

Fig. 1. Guideline values of the conservation factor (CF).

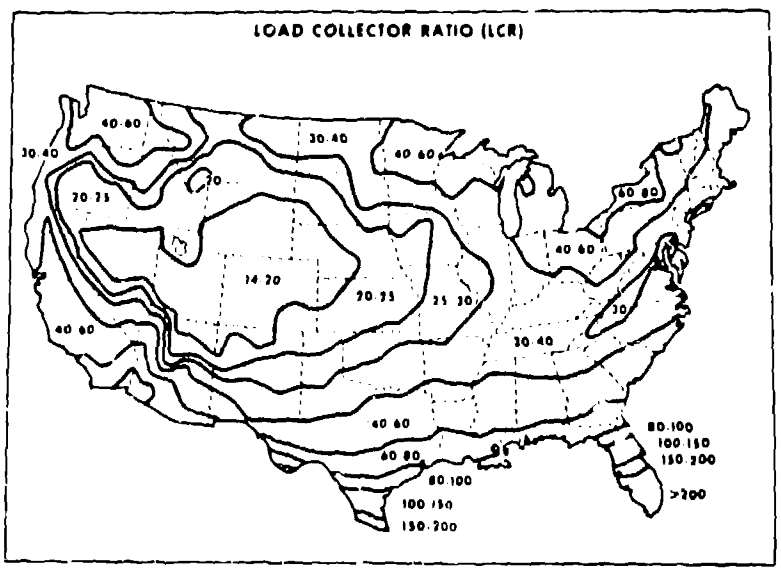

Fig. 2. Guideline values of the load collector ratio (LCR).

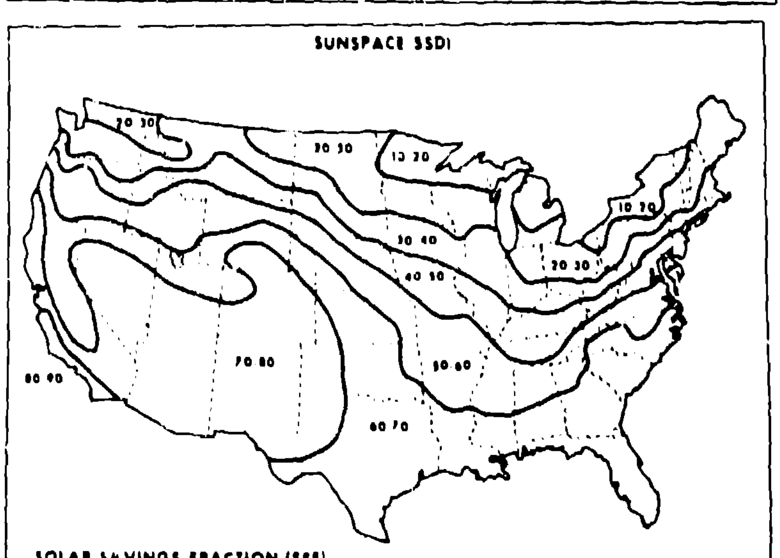

Fig. 3. Solar savings fractions for the guideline values of LCR for a semienclosed sunspace with 50° sloped glazing (reference design SSD1).

SSF was determined using the solar load ratio method.

A complete development of the equation for GF, the geometry factor, cannot be given here because of space limitations. It follows from the equations in Ref. 3.

Table I was developed by specifying passive system type SSD1 and then finding values of LCR such that the following values of D would result:

high fuel cost	D = 30,000/DD
low fuel cost	D = 60,000/DD

Because D = a/h = (a · FCR)/(CH · FF · DD), this implies the following ratios:

high fuel cost	(a · FCR)/(CH · FF) = 30,000,
low fuel cost	(a · FCR)/(CH · FF) = 60,000.

Values for CF, LCR, and SSF in Table I correspond to any values of a, FCR, CH, and FF that satisfy these conditions. One particular set of values is as follows:

a = $10/ft^2
FCR = 0.1 yr^{-1}
CH = $22.22/MMBtu (high heat cost)
CH = $11.11/MMBtu (low heat cost)
FF = 1.5

Obviously many other choices could have been made that would satisfy the equation for D.

The following incremental conservation costs were used:

wall insulation	0.05	\$/R-ft^2
ceiling insulation	0.03	\$/R-ft^2
perimeter insulation	0.25	\$/R-lineal ft
basement insulation	0.50	\$/R-lineal ft
E,W,N windows	4.00	\$/glazing
infiltration reduction	0.0312	\$/HAC-ft^3

where HAC = 1/ACH represents the hours per air change.

9. COMMENTS REGARDING PASSIVE SYSTEM SELECTION

The rationale for choosing the semienclosed sunspace system, SSD1, for developing Table I is based on observing the nature of the results. The LCR values that are obtained for the high fuel cost case are reasonably close to the overheating limit in US cities where winter overheating might be a problem, and are close to buildable limits in cold, sunny climates. They lie between results obtained for other systems. Thus, the criteria used in developing Table I are reasonably compatible with other criteria that might have been used instead.

The double glazed, semienclosed sunspace system SSD1 is a good performer throughout US climates without requiring night insulation (although performance is considerably improved with night insulation). Whereas we desired to avoid requiring night insulation in developing a general guideline, night insulation (or a selective surface on a water wall or Trombe wall) may well be advisable in cold climates.

10. BASE TEMPERATURE CALCULATION

The base temperature used for calculating degree days needed to develop Table I was adjusted over a range of approximately 55-67°F to account for internal heat generation. The internal heat rate assumed is 47 Btu/day per ft^2 of house, as might be associated with a residential application, and the thermostat setpoint assumed is 70°F.

11. REFERENCES

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